Living and Sustainability: An Environmental Critique of Design and Building Practices, Locally and Globally

AMPS, Architecture_MPS; London South Bank University
09—10 February, 2017

SIMULATION OF TRADITIONAL & CONTEMPORARY DWELLINGS IN GHADAMES, LIBYA

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ABSTRACT

A rise in temperature over summer in hot countries, such as Libya, may lead to thermal discomfort and profligate use of energy sources as a result of mitigation efforts. Buildings account for almost 45% of global energy consumption, and approximately 60% of primary energy use in Libya. The use of air conditioning systems have resulted in a sharp rise in energy consumption and CO2 emissions. Traditionally, bioclimatic design concepts have been applied and integrated into buildings in hot climates to reduce the demand of energy consumption, but increasingly less adapted designs of housings developed elsewhere are prevalent. This results in energy being excessively used in order to achieve human thermal comfort requirements. The purpose of this work is to investigate the environmental performance of naturally ventilated (NV) and air conditioned (AC) dwellings in Ghadames and the impact of bioclimatic concepts on energy use for future housing development. A range of EnergyPlus simulations were carried out to predict the indoor climate conditions and energy consumption of typical NV and AC dwellings considering different scenarios including the case of electrical power cuts. Findings revealed that traditional dwellings consume 66.1% less energy than contemporary dwellings. The thermal comfort surveys of Ghadames housing indicated that comfort temperature in NV buildings ranges between 24˚ to 32˚C and 22˚C to 26˚C in AC buildings in summer. Further findings from simulation showed that building fabric and form of traditional dwellings perform far better than contemporary dwellings in terms of solar heat gains, thermal performance of materials, land use and natural ventilation. The study concluded that consolidation of certain passive design features found in traditional dwellings of Ghadames and use of appropriate architectural design and elements can help achieve zero energy housing, taking into account local community needs and future developments.

***Key words**: Bioclimatic design, EnergyPlus, desert architecture, energy efficiency, thermal comfort.*

BACKGROUND

The study of traditional and contemporary settlements may have been addressed in a number of publications worldwide whilst in Libyan context is still not widely reflected (Chojnacki, 2003). These topics usually were discussed in narrow sections or carried out by individuals who so often enchanted by and interested in to document the beauty of old solutions. Discussing the discord between old and new solutions needs deeper understanding of their form, elements, functions and the role of context considering the social mores and microclimatic conditions. Ghadames consists of two types of settlements as one represents traditional type of architecture found in the old town and the second is modern urban settlements expressing the contemporary architectural forms in the new town. In literature these types of settlements may defined as naturally ventilated buildings and mechanically conditioned buildings. Energy resources and environmental pollution are the main challenges of new constructions as the first accounts for 45% worldwide and 30% for gas emissions in buildings alone (Zhai and Previtali, 2010). 36.18% of primary energy in Libya is consumed in domestic buildings whilst 75.36% of this energy is used for space cooling mainly in summer (GECOL, 2012). Thus, buildings produce more CO_2, generate more pollution, consume more energy and waste more natural resources than any other industrialized sectors (Sozer, 2010).
However, these global figures spurs this research to investigate the issues related to the building form, energy use and the possibility to apply passive means to reduce or to generate energy from alternative sustainable sources. Computer simulation programs became important tools for evaluating not only

energy performance of existing and newly building designs but rather assessing the whole process of the design, operating system and lifecycle maintenance of the building. In addition, human thermal and visual comfort can be also assessed using such tools by carrying thermal and daylighting analysis. According to Fasi and Budaiwi (2015) there are many building program software (BPS) worldwide used to simulate the energy and thermal performance of a building including EnergyPlus. The EnergyPlus engine tool which was developed by the American Department of Energy helped DesignBuilder to pass three major tests (the analytical, comparative and executable tests) to comply with today's industry needs (Dabaieh et al., 2015). Typical traditional and modern dwellings were modelled based on defined characteristics from previously conducted surveys for the purpose of simulation to test both the validity of the tool and evaluate the energy and environmental performance of these buildings. The study carried out methods of field survey investigation to inform the simulation and analysis including temperature measurements and observation of householders' behavior and preference.

GEOGRAPHICAL AND CLIMATE FEATURES

Ghadames town is located in the north east of the Sahara Desert. The town was built over 400 years ago on an Oasis that lies approximately 630 km to the south-west of Tripoli close to the junction between Libya, Tunisia and Algeria (Chojnacki, 2003). The climate characterized with high temperature records, high and dense solar radiation, low relative humidity rates and zero rainfall in summer whilst relatively cold winters especially at night. In addition, the daily diurnal temperature is high particularly in summer time and the sky condition is sunny and clear almost throughout the year.

TYPICAL MODEL OF TRADITIONAL HOUSE

Dan Amazagra is the name the traditional house was surveyed during field visit to Ghadames city. The house is consists of three storeys with one storage room on ground floor, three bedrooms and one central living room and toilet in first floor, kitchen and loggia on roof level. However, this typical traditional house is compact in form and has similar space organization arranged in a vertical layout as most of houses in the old town of Ghadames as Figure 1 shows. Also these houses are oriented towards the covered alleyways as main entrance and having roofs attached to each other offering a pathway for women to move from building to another.

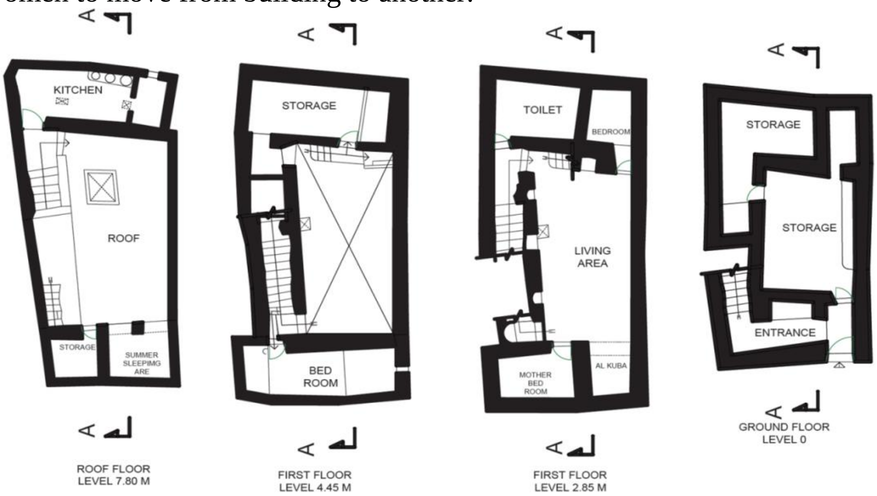


Figure 1. Plans of typical traditional house

Construction materials

Building material is one of the key aspects characterizes the desert architecture which so often called adobe architecture in some literature. The selection of specific material and method of construction was not a choice of people rather influenced by many factors predominantly the ecological land cover especially the abiotic elements such as soil, climate and other geological conditions. Equally importantly, the economic structure of society and inherited experience and knowledge of construction methods and techniques have an impact on the way local dwellings were built. Technically, walls are made out of sun-dries mud bricks with approximate digestions of 12×40× (75, 60, 50)cm as the thickness of the wall varies starting at 75cm on ground level to change at height of 3m to 60cm and then to 50cm at height of 5 to 6m (Al-Zubaidi, 2002 and Allafi, 2012). According to Gabril (2014) the roof materials of the traditional house indicated high thermal performance with a heat transfer value of 0.402 W/m^{2}k as shown in Table 1 shows. Al-Zubaidi (2002) stated that rocks and mud are the most common building materials in the old town of Ghadames due to the nature of the desert land.

Table 1. Roof construction materials of traditional house

Ext	Material description	Thickness	Conductivity	Density	Specific heat
1	Sand stone mixture	150	1.83	2200	712
2	Palm tree leaves (mat)	30	0.083	1800	180
3	Palm tree wood	150	0.08	600	2000
In	U-value		0.402 W/ m^2.K		

TYPICAL MODEL OF CONTEMPORARY HOUSE

The model shown in Figure 2 is a typical two storey house in Tukash neighborhood located in the new part of Ghadames city. It represents one of the first housing project schemes launched in early 1980s by Libyan government in Ghadames consisted of over 600 housing units designed by Polish architects Mika Ratshiva and Andrzej Zukowaski and constructed by Turkish company (Ben-Swessi,1993). The house consists of one living room, kitchen, two bathrooms and three bedrooms.

Figure 2. Plans of typical contemporary house

Construction materials

It can be said that construction materials used in contemporary houses in Ghadames are the same used in other Libyan cities characterized with the use of cement, concrete, tiles and ceramic in light weight constructions with high heat transfer values (U-value). Building walls in Ghadames are constructed of concrete cavity blocks and can be found in different thickness and size ranges from 150-250mm with conductivity 0.55-1.2W/m deg. ˚C, Density 1800-2240 Kg/m^3 and specific heat capacity 650- 880 J (Kg deg. ˚C) as shown in Table 2.

Table 2. Wall construction materials of contemporary house

Ext	Material description	Thickness mm	Conductivity W/m	Density	Resistance
1	Cement & sand light	12	1.0	1000	0.012
2	Concrete cavity block	200	0.7	1900	0.357
3	Cement & sand light	12	1.0	1000	0.012
In	U-value	**2.083 W/ m^{2}K**			

According to Gabril (2014) the U-value of walls in Ghadames dwellings found to be slightly higher than what have been found in this study at 2.648 W/m^{2}K whereas roof U-value was at 2.016 W/m^{2}K due to using insulation materials as she claimed. These input data were carefully studied as it has great impact on the simulation outcomes. Table 3 shows the contemporary roof construction materials and its thermal properties.

Table 3. Roof construction materials of contemporary house

Ext	Material description	Thickness mm	Conductivity W/m	Density	Resistance
1	Floor tiles	10	0.8	550	0.013
2	Cement mortar	20	0.94	2000	0.021
4	Concrete slab	200	0.57	2200	0.175
6	Cement mortar	20	0.88	2100	0.015
In	U-value	**2.791 W/ m2K**			

SIMULATION AND FINDINGS

EnergyPlus alongside with some other tools such as Radiance and SBEM were chosen to carry out a thermodynamic and energy simulation for existing typical traditional and modern houses to compare their energy and environmental performance. The tools are integrated in an interface program (DB) provides one of the greatest confidence in results and capable to test the annual cooling/heating loads and various control strategies with the ability of assessing overheating risk in buildings (BRE, 2009).

Analysis of traditional house

The model was simulated based on the following building information input data shown Table 4 . The window-to-floor ratio (WFR) has been calculated for this typical house and found to be 0.018 whilst the window-to-wall ratio was approximately 2.6% which is far less than recommended ratio for hot climate buildings by for example Mandilawi (2012) which is 15%.

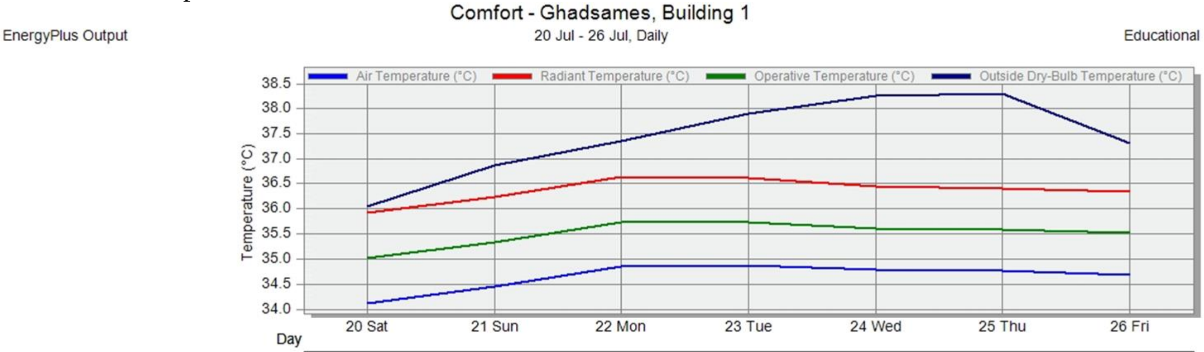
Table 4. Traditional house base input data

Category	Input data
Climate	Desert Climate
Building orientation	0-0
Constructional materials	Traditional building materials
Building height	9.7m
Total ground floor area	24.142 m^2

Total first floor area	31.95 m^2
Total mezzanine floor area	11.55 m^2
Total roof area	29.86 m^2
Glazed area	0.0 m^2
Surface-to-volume ratio	43.82/234.79 = 0.186
Occupancy density (people/area)	8/67.84 = 0.118 p/ m^2
Building systems	Natural ventilation

Indoor thermal conditions

Simulation was run for typical summer week in July and also for the whole year to compare results with actual temperature readings. Figure 3 demonstrates that air temperature (T_a) estimated around 34.5˚C throughout typical summer week due to high radiant temperature and low humidity rates. The figure also shows that PMV model predicted the indoor comfort conditions to be out of the recommended zone. In fact, field surveys carried out inside this house and found that residents were feeling comfortable at high temperature records 29˚C to 32˚C. This can be referred to the microclimate of the old town owing to the green fields and water content contributed to humidify and drop down ambient air temperature which has not been accounted in the simulation.



Air Temperature (°C)	34.14	34.46	34.85	34.87	34.80	34.78	34.70
Radiant Temperature (°C)	35.92	36.24	36.63	36.61	36.44	36.40	36.34
Operative Temperature (°C)	35.03	35.35	35.74	35.74	35.62	35.59	35.52
Outside Dry-Bulb Temperature (°C)	36.05	36.86	37.34	37.89	38.24	38.28	37.31
Relative Humidity (%)	8.14	10.02	10.39	8.01	10.67	15.47	19.24
Fanger PMV ()	2.85	2.99	3.13	3.09	3.08	3.14	3.16

Figure 3. Indoor thermal conditions in typical traditional house

Heat gains and total energy consumption

Internal and external heat gains can highly contribute to the energy consumed inside buildings especially in extreme climate conditions. In Ghadames solar radiation is relatively high and old town settlements were designed for minimum solar direct heat gains as most buildings stand wall to wall by all sides as can be seen in Figure 4. The figure also shows that lighting is the main consumer inside the house and water pumps were installed later as part of the house modification to meet locals' needs. The total annual energy use inside the traditional house estimated at 28.87kWh/m^2. According to Noguera and Cervera (2012) PassiveHaus specified that the annual total energy demand for space requirements should be limited to 20-30kWh/m^2.

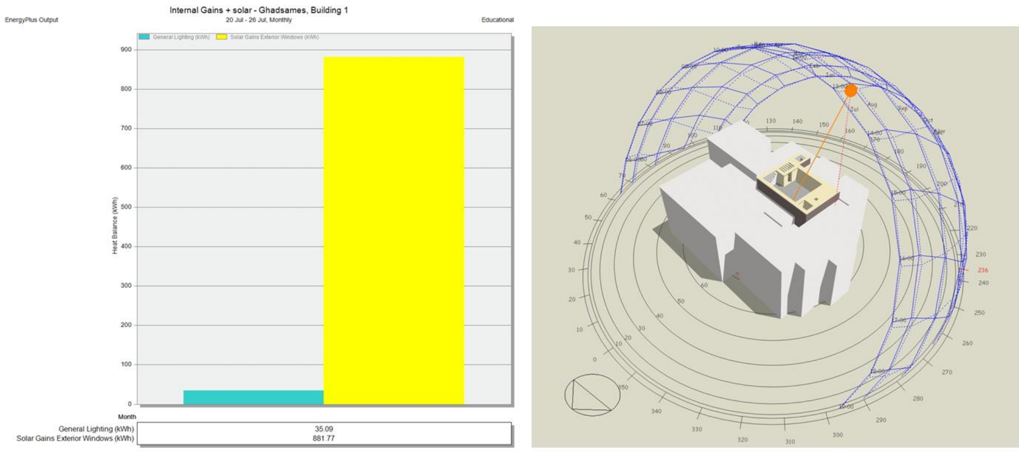


Figure 4. Total energy consumption and solar heat gains in typical traditional house

Daylighting

Radiance has been considered as one of the best tools to test the sufficiency of daylighting which is integrated into CIBSE and LEED calculations. in practice daylight factor of 2% to 5% showed to have great balance between achieving good daylighting and thermal aspects (CSH, 2010). BREEAM Credit HEA1 aims to encourage and recognize designs that provide appropriate levels of daylight for building users.

A pass requires that both the following conditions are met:

- At least 80% of net lettable floor area in occupied spaces is adequately day-lit, having an average daylight factor of at least 2% at the working plane height of 0.7m under a uniform CIE overcast design sky;
- A uniformity ratio of at least 0.4 or a minimum point daylight factor of 0.8% (spaces with glazed roofs, such as atria, must achieve a uniformity ratio of at least 0.7 or a minimum point daylight factor of at least 1.4%).

Results indicated no compliance with minimum standards set in BREEAM calculations and the house fail to be adequately lit naturally. However, by looking at the most used space inside the house (the central hall) results indicate that an average of daylight factor has been achieved at 3.21% but rather poor daylight distribution as shown in Table 5.

Table 5. Daylighting performance in typical traditional house

Summary Results	
Total area (m2)	67.010
Total area above threshold (m2)	15.190
% Area above illuminance threshold	14.52
Criterion a) 80% of area adequately day-lit	FAIL
Criterion b) Uniformity ratio >= 0.4, min DF = 0.8%	FAIL
BREEAM Health and Wellbeing Credit HEA1 Status	FAIL

Zone	Block	Floor area	Min DF (%)	Uniformity ratio	Area adequately	Average
Toilet	first floor	6.320	0.00	0.00	1.82	1.6
Living-	first floor	17.68	0.00	0.00	5.67	3.21
Cesspit	ground	4.75	0.00	0.00	0.00	0.0
Total		**28.750**				

Analysis of contemporary house

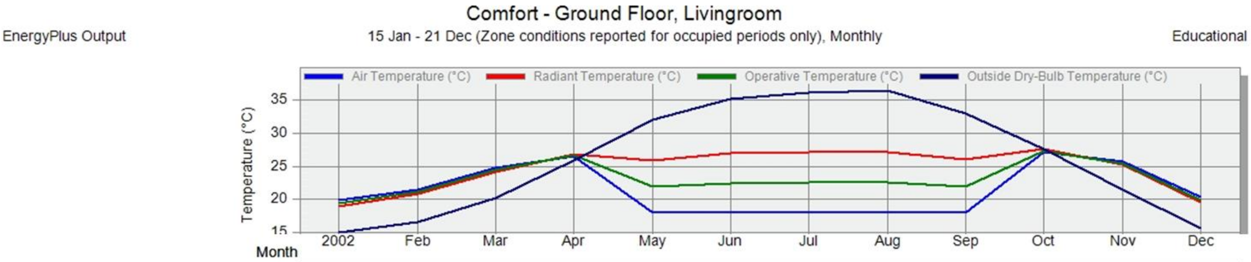
The main input data for the simulation is based on the model information which is shown in Table 6.

Table 6. Contemporary house base input data

Category	Input data
Climate	Desert Climate
Building orientation	0-North
Constructional materials	Contemporary building materials
Building height	6 m
Total floor area	108.290 m2
Total roof area	61.40 m2
Glazed area	16.520 m2
Surface-to-volume ratio	260.8/333.9 = 0.781
Occupancy density (people/area)	4/108.29 = 0.037 p/ m2
Building systems	Air conditioning systems (HVAC)

Indoor thermal conditions

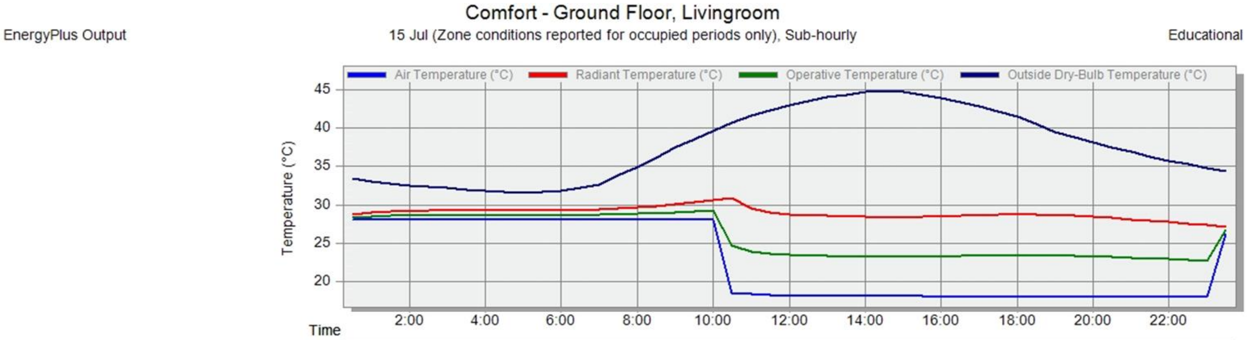
Surveys indicated that contemporary dwellings in Ghadames use mechanical cooling and heating systems to achieve indoor comfortable conditions. Householders and professionals confirmed that AC is used around April to October every year and from the figure it can be understood why residents start using AC at that time. Figure 5 indicates that the average outdoor air temperature started to rise above 25˚C in April and drops back to similar degree around October. The system clearly achieved comfort conditions as operative temperature is maintained within the comfort zone between 19˚C to 27˚C. These findings relatively agree with field temperature measurements where indoor air temperature was recorded between 24˚C to 26.5˚C inside the contemporary houses.



	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	19.88	21.55	24.74	26.62	18.00	18.01	18.00	18.00	18.00	27.16	25.70	20.36
Radiant Temperature (°C)	19.04	20.81	24.13	26.83	25.94	26.95	27.11	27.15	26.03	27.64	25.21	19.56
Operative Temperature (°C)	19.46	21.18	24.44	26.72	21.97	22.48	22.56	22.57	22.01	27.40	25.46	19.96
Outside Dry-Bulb Temperature (°C)	15.07	16.67	20.28	25.86	32.05	35.24	36.21	36.44	33.05	27.59	21.57	15.71
Relative Humidity (%)	27.69	26.04	24.07	23.04	38.09	36.91	27.58	35.18	41.90	22.52	20.24	37.03
Discomfort hrs (all clothing) (hrs)	98.25	98.00	27.00	83.50	9.75	4.75	0.00	0.00	0.75	112.00	20.50	96.50
Fanger PMV ()	-1.54	-1.06	-0.15	-0.36	-2.22	-2.04	-2.07	-2.02	-2.19	0.64	0.11	-1.33

Figure 5. Indoor thermal conditions in contemporary house in annual base

On a daily base the majority of householders during field surveys and investigations stated that AC is switched on at around 10:00 am to 23:00pm for approximately 12 to 14 hours a day. Outside temperature drops down late evening until early morning as the Figure 6 shows. This reveals that those occupants started using AC at the right time when indoor radiant temperature begin to rise until clearly outdoor temperature begin to have downtrend course.

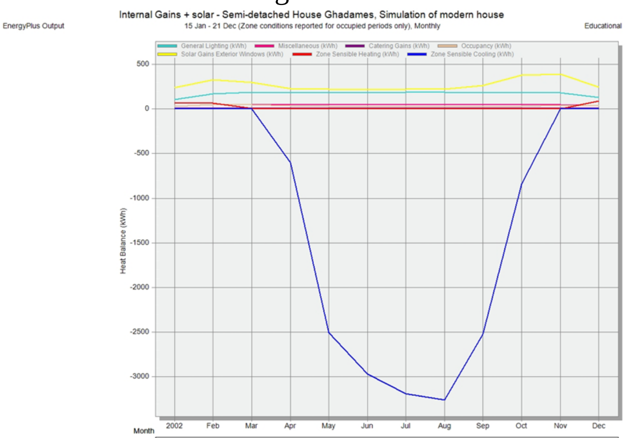


Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Air Temperature (°C)	28.00	28.00	28.00	28.00	28.00	18.15	18.04	18.01	18.00	18.00	18.00
Radiant Temperature (°C)	29.19	29.26	29.24	29.65	30.59	28.79	28.39	28.46	28.73	28.44	27.74
Operative Temperature (°C)	28.59	28.63	28.62	28.83	29.29	23.47	23.22	23.24	23.37	23.22	22.87
Outside Dry-Bulb Temperature (°C)	32.56	31.76	31.76	34.93	39.68	42.98	44.70	43.91	41.53	38.10	35.72
Relative Humidity (%)	18.29	18.26	18.25	18.25	18.24	33.12	33.35	33.41	33.46	33.56	33.66
Mech Vent + Nat Vent + Infiltration (ac/h)	0.69	0.69	0.69	0.68	0.67	0.65	0.64	0.64	0.65	0.65	0.66

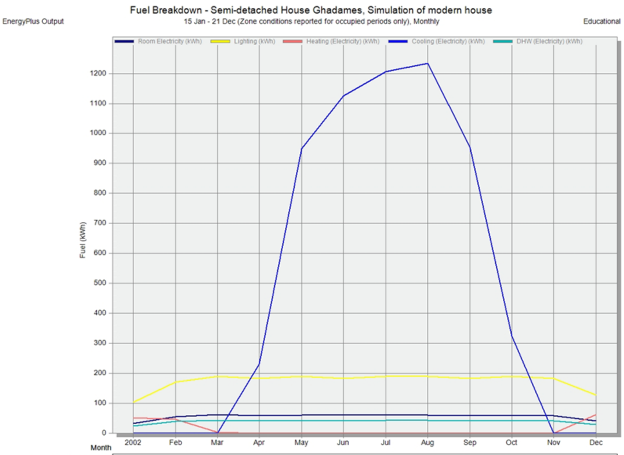
Figure 6. Indoor thermal conditions in typical contemporary house in daily base

Heat gains and total energy consumption

In dominantly cooling demand regions the design for minimum internal heat gains is a key of importance for efficient energy building designs. Figure 7 reveals that solar heat gains is less during summer as the sun-angle being higher on vertical surfaces and lower in winter which increases the internal heat gains. Simulation results also showed that space cooling brings the highest energy bills to the house at an annual rate of 9201.57kWh/108m2 = 85.19kWh/m2. According to Carmody et al. (2009) the total energy usage in a residential building should not exceed 20-30kWh/ m2 per year in total primary energy for space cooling base on European Standards. Two main reasons were found during the surveys for using artificial lighting most of the day in contemporary housing; privacy and absence of solar shadings for windows.



Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
General Lighting (kWh)	103.44	170.28	188.45	182.48	188.58	182.35	188.58	188.94	182.00	188.58	182.84	127.71
Miscellaneous (kWh)	27.49	45.72	50.99	48.81	50.35	49.45	50.35	50.67	49.13	50.35	49.13	34.29
Catering Gains (kWh)	5.29	8.72	9.65	9.34	9.65	9.34	9.65	9.65	9.34	9.65	9.34	6.54
Occupancy (kWh)	29.70	47.32	45.84	33.63	28.50	22.63	22.73	22.01	24.57	28.43	39.48	36.51
Solar Gains Exterior Windows (kWh)	241.21	327.72	295.16	229.73	222.20	213.21	219.79	224.31	264.80	376.28	390.23	246.52
Zone Sensible Heating (kWh)	70.32	62.54	5.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	86.72
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	-599.65	-2506.91	-2972.12	-3187.42	-3260.06	-2521.57	-842.16	0.00	0.00



Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Room Electricity (kWh)	32.78	54.44	60.64	58.15	60.00	58.79	60.00	60.32	58.47	60.00	58.47	40.83
Lighting (kWh)	103.44	170.28	188.45	182.48	188.58	182.35	188.58	188.94	182.00	188.58	182.84	127.71
Heating (Electricity) (kWh)	51.44	45.34	3.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.48
Cooling (Electricity) (kWh)	0.00	0.00	0.00	231.43	948.97	1125.34	1206.25	1233.64	954.65	324.11	0.00	0.00
DHW (Electricity) (kWh)	23.37	38.49	42.62	41.24	42.62	41.24	42.62	42.62	41.24	42.62	41.24	28.87

Figure 7. Internal heat gains and total energy use in typical contemporary house

Daylighting

The window to wall ratio WWR in this semi-detached house found to be 10.4% which more likely will provide inadequate daylighting. Inside the living room average daylight factor is assumed to be at 1.9% with the use clear glass and no window blinds installed. Daylighting simulation using BREEAM calculations in DesignBuilder is shown in table 7. The overall daylight performance of the house shows no compliance with internal standards with approximately 23% of internal zones adequately lit through natural lighting. This figure denotes how poor the window design in contemporary housings which in turn have great impact on human visual discomfort and energy compensated by artificial lighting.

Table 7. Daylighting performance in typical contemporary house based on BREEAM calculation

Summary Results	
Total area (m2)	108.290
Total area above threshold (m2)	24.930
% Area above illuminance threshold	23.0
Criterion a) 80% of area adequately day-lit	FAIL
Criterion b) Uniformity ratio >= 0.4, min DF = 0.8%	FAIL
BREEAM Health and Wellbeing Credit HEA1 Status	FAIL

CONCLUSION

This research introduced the simulation analysis of the two models representing a typical traditional and modern housing of Ghadames. EnergyPlus has been chosen for number of reasons including the flexibility, accuracy and capability of using high performance engine tools. This analysis process is to compare the old and new settlements' energy and environmental performance and also to infer the positive aspects of both dwellings in terms of achieving comfort design conditions. However, results showed that neither traditional nor modern dwellings have achieved comfortable indoor conditions according to ASHRAE and CIBSE standards in terms of thermal and visual comfort and indoor housing conditions requirements.

To conclude there is a need to develop the existing housing designs to meet local community aspiration and respond to local climate. This can be only achieved by considering the local conditions in design, construction and operations phases which means selecting the right material, layout design, passive climatic strategies and utilizing the right technology for environmentally and energy efficient housing. The design of future housing in Ghadames and hot arid regions in general requires great attention as existing models are highly dependent on mechanical systems and nonlocal building styles that noticeably reflect foreign culture and way of life.

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